Detailing of timber structures in seismic areas

STEP lecture D10
A. Ceccotti
University of Florence
P. Touliatos
University of Athens

Objective

To give guidelines for the design and evaluation of structural details for timber construction in seismic zones.

Summary

Structural detailing is a very important issue for earthquake resistant buildings. This is particularly true in the case of timber structures where the conception of the structural behaviour as a whole and of single joints play fundamental roles. In this lecture particular attention is therefore paid to the structural form and to the ductility and dissipation properties of joints that can be reached only if details are properly conceived. The intention is not to present an exhaustive list of possible cases but to give the key for a better understanding of real needs. Examples are taken also from ancient constructions in order to enable modern designers to learn from past experience about earthquake-safe constructions, when calculation codes were not yet available.

Introduction

In the design process of construction in seismic zones great attention is always paid to the calculation of the load-bearing elements: codes dedicate a large space to it. Nevertheless designers must be aware that the diligent application of the calculation rules will not be enough for the success of the construction. The reality is that constructional arrangements and details are also important. In other words calculation per se is not sufficient without good detailing. Eventually the opposite may be true; i.e. for constructions of small dimensions, regularly arranged in plan and in height, with some minimum dimensioning of element sections, few guidelines about bracing and connections had been in general sufficient, as shown by experience, to resist earthquakes. Therefore in many seismic codes around the world a list of minimum dimensions and requirements with structural examples are given for small structures which do not need to be calculated (Ceccotti, 1989).

In the present version of the European Seismic Design Code (Eurocode 8) a similar possibility has been not considered because of the diversity of construction techniques through different countries of the European Union. Anyway in Eurocode 8 in addition to calculation criteria a lot of detailing rules are given in order to:

- assure compliance with some very important hypotheses which form the basis of the calculation methods and to give at the same time advice against the most dangerous mistakes;
- assure the attainment of the required ductility level and, consequently, of the relevant "behaviour factor" used for the evaluation of the inertia forces. For example in part 1.3, chapter 5 - "Timber Structures" - of Eurocode 8 some detailing rules are given in order to assure good ductility behaviour of the mechanical joints.

Actually, in order to avoid limiting the building activity with timber, Eurocode 8 is a performance-based code and in principle any joint may be acceptable if it fulfils some ductility performance test requirements (see STEP lecture C17), but in most current cases a few detailing rules are sufficient to avoid tests.

Nevertheless the designer must also be aware that even if the part of the code dedicated to detailing was to be full of structural detailing examples a satisfactory outcome is not assured by the uncritical application of these rules. The most important thing is to understand the real meaning of such detailing rules and behave accordingly. A code could never contain and solve respectively all kinds of details and problems. Consequently, in this lecture the principal idea is to focus on the most important points to be controlled for the best performance of a generic timber structure in a seismic zone and leave the solution of particular cases to the designer.

Structural continuity

Basically, the earthquake action may be considered to be a horizontal action that, in contrast to vertical actions, involves the entire structure and not only the small part of it just underneath the load (Figure 1). Obviously the same thing can be said for wind, but if hurricanes are excluded, fortunately not present in Europe, the action of the earthquake, according to the modern point of view of the Eurocodes, can be more important than wind especially for heavy structures (Ceccotti & Larsen, 1988).

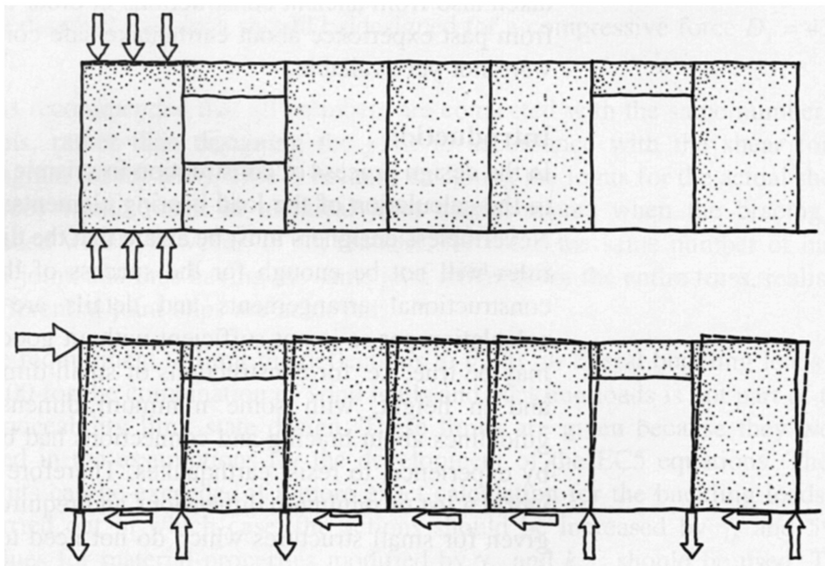

Figure 1 Different structural effects of vertical and horizontal loading.

This means that the continuity of the link between different members at all positions is particularly important and the effectiveness in both tension and compression. All the components of the shear walls and diaphragm systems (see STEP lecture E10) must be adequately fastened together so that the structure acts as an effective unit.

In Figure 2, for example, the main positions where such features are necessary are focused, and a possible solution for realising continuity is presented. At the floor level the presence of a continuous girder all around the floor should be considered in order to collect the tension forces that will arise when the floor is loaded laterally and it is considered rigid in plan acting as a diaphragm (Figure 2b); and the necessary continuity at the corners will be assured through the diaphragm panelling putting edge nails at closer spacing (Figure 2a).

Also in the height the load bearing vertical elements should be continuously connected in order to guarantee the transmission of the vertical efforts (Figure 2c).

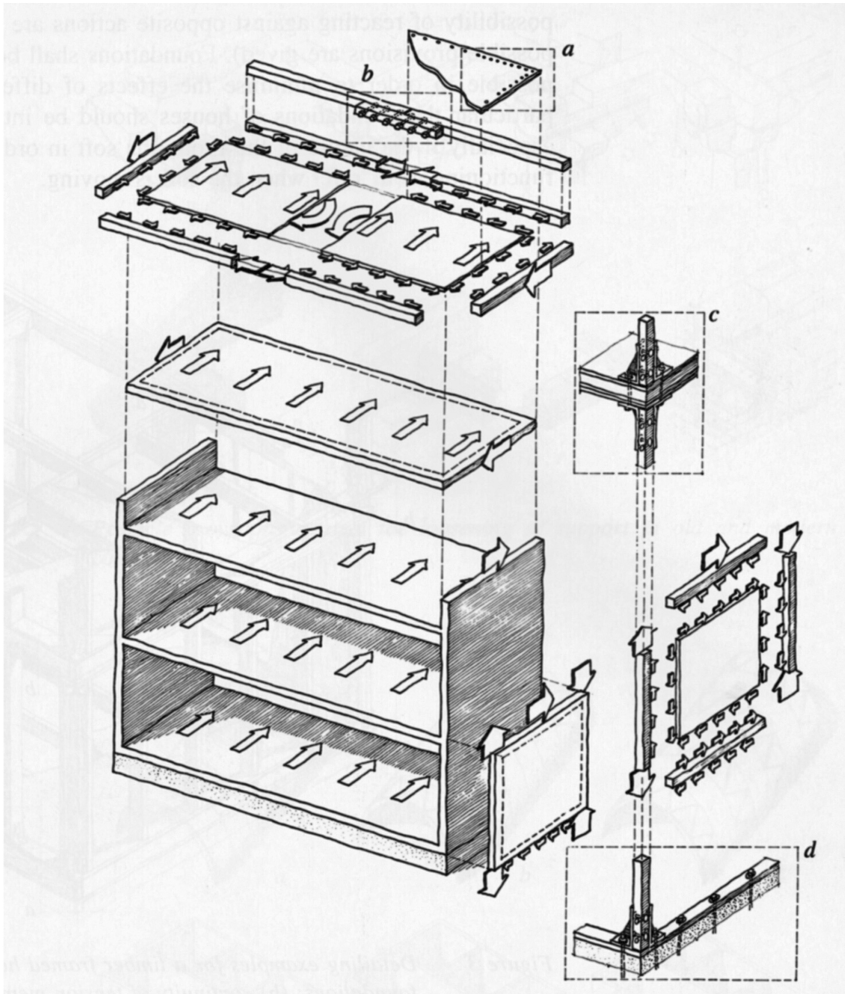

Figure 2 *Details assuring structural continuity under horizontal actions. (a) corner reinforcement; (b) tension girder continuity; (c) continuity of tension studs; (d) prevention of uplifting from foundation and sliding of foundation.*

In some cases, at floor level, the liaison between two corresponding - upper and lower - shear walls is merely obtained by panel sheeting nailing through the header beam of the floor. That is not suitable when tension efforts are important as in the case of an earthquake (e.g. a good solution is shown in Figure 2c and Figure 3b). Particular attention should be paid to the connections between the timber structure and the foundations both in order to prevent uplift and sliding (Figure 2d). Openings weaken both diaphragms and shear walls, therefore openings must be reinforced around them in order to maintain as much as possible the same in-plane rigidity. In Figure 3 an example of a real application is given.

Great attention shall be paid to tension perpendicular to grain. For that reason Eurocode 8 prescribes, with reference to Figure 4d, that b_e has to be more than 2/3 h, where h is the depth of the member, so that splitting due to tension perpendicular to the grain is less likely; and when using a strap this should surround the timber piece (Figure 4e).

Connections must obviously be able to work in both directions because the action of the earthquake is bi-directional. For that reason simply contact joints without any possibility of reacting against opposite actions are not suitable (in Figure 5 some possible provisions are given). Foundations shall be tied to each other as much is possible in order to minimise the effects of differential ground movements. In particular the foundations of houses should be interconnected to act as a whole especially if the nature of the ground is soft in order to realise a rigid foundation functioning as a "raft" when the soil is moving.

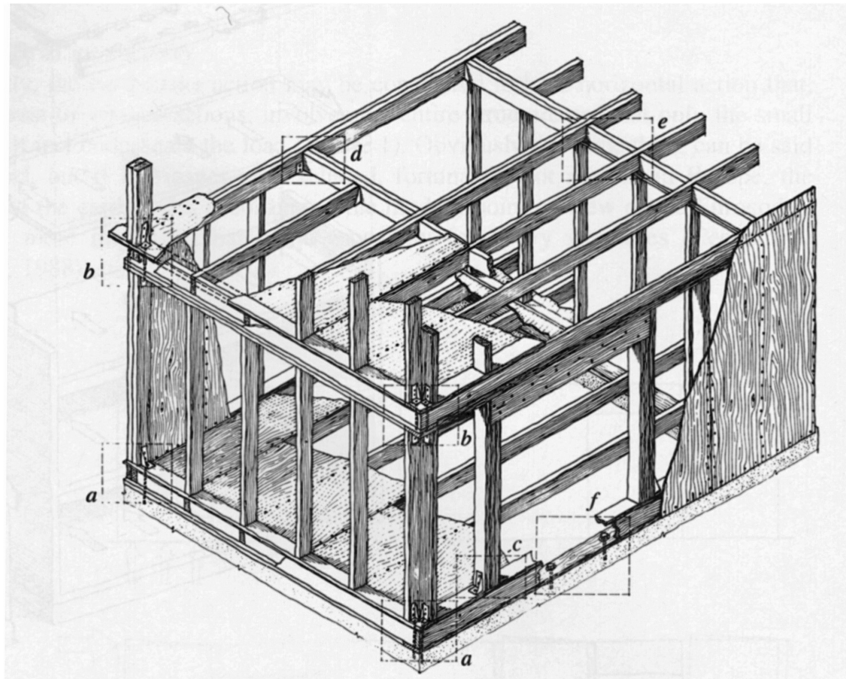

Figure 3 *Detailing examples for a timber framed house. (a) prevention of uplift from foundations; (b) continuity of tension members; (c) stiffening of openings in shear walls by framing with additional studs, lintels and corner hangers; (d) stiffening of openings in diaphragms by framing with doubling of trimmer and header joists; (e) stiffening of diaphragm floors (blocking); (f) prevention of sliding of foundations.*

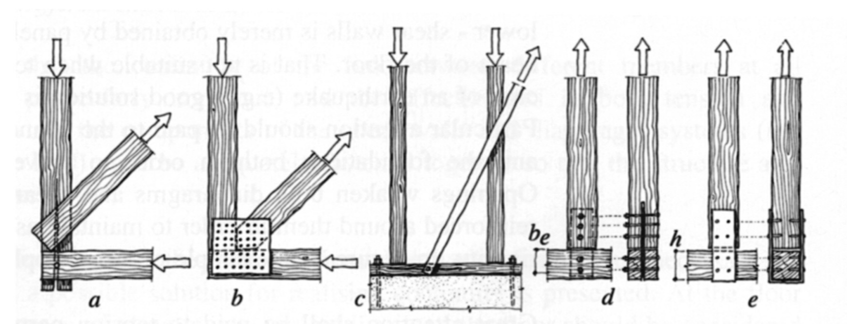

Figure 4 *Detailing against tension perpendicular to grain. (a),(c): poor; (b),(d) and (e): good.*

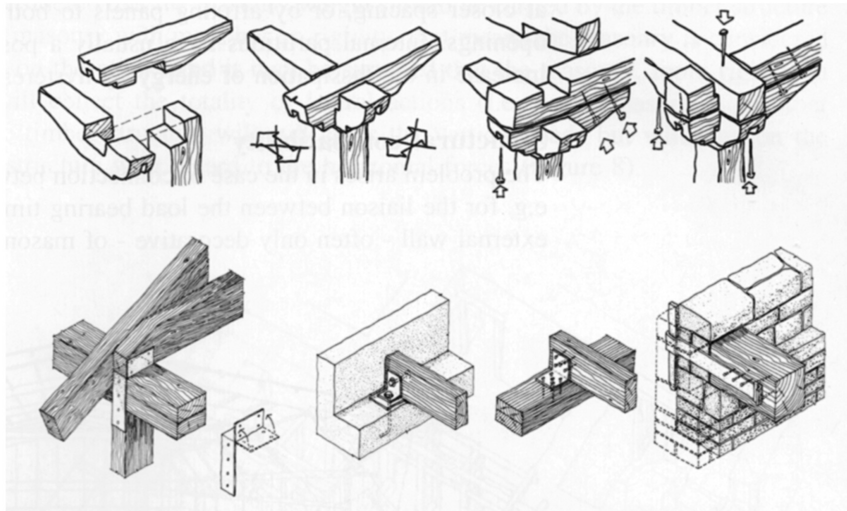

Figure 5 *Possible provisions against the loosening of support in old and modern constructions.*

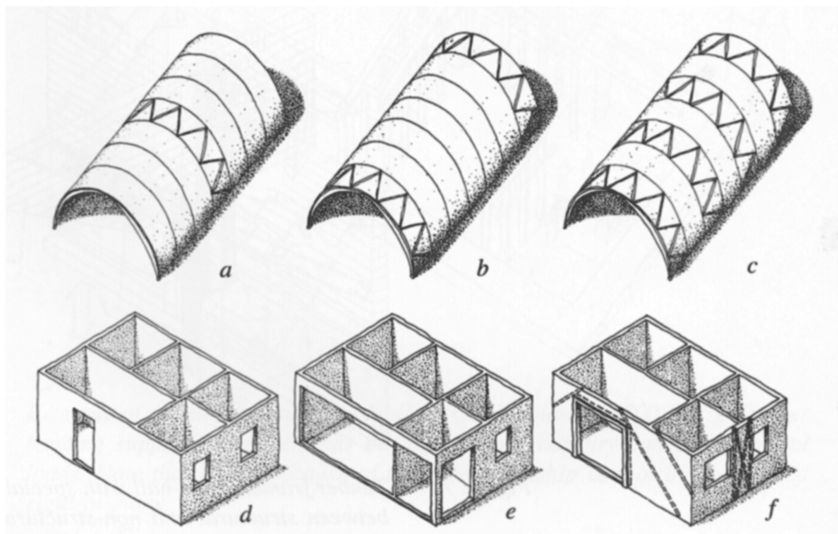

Figure 6 *Schematic examples of distribution of bracing and stiffening. (a) and (e): poor; (b) and (f): fair; (c) and (d): good.*

Building regularity

Regularity in plan and height is very important in order to assure good behaviour under earthquakes. The reason is that torsional effects induced by irregularity are not easily determined by the calculations, especially the static one. On the other hand, unfortunately, the attempt to control torsional effect by sophisticated dynamic calculations is often no more than an academic exercise: it would be much better to realise the regular building, also without real axes of symmetry but at least with seismic resistant parts regularly distributed and, better, also homogenously distributed (Figure 6, rearranged from Dowrick, 1977). In that way torsional effects are quite limited, strength properties are more uniformly distributed and calculation results more reliable. In the presence of large unbalanced openings in order to reduce the tendency of the building to twist under lateral forces, the best solution is to try to approximate the rigidity afforded by the shear wall at the opposite end by means of additional bracing, or by increasing panel thickness, with edge nailing at closer spacing, or by affixing panels to both sides of the framing around the openings. Internal partitions have usually a positive effect as they contribute an increase in the dissipation of energy by hysteresis and friction.

Structural compatibility

The problem arises in the case of connection between parts with different rigidities, e.g. for the liaison between the load bearing timber structure and a chimney or an external wall - often only decorative - of masonry (or even glass).

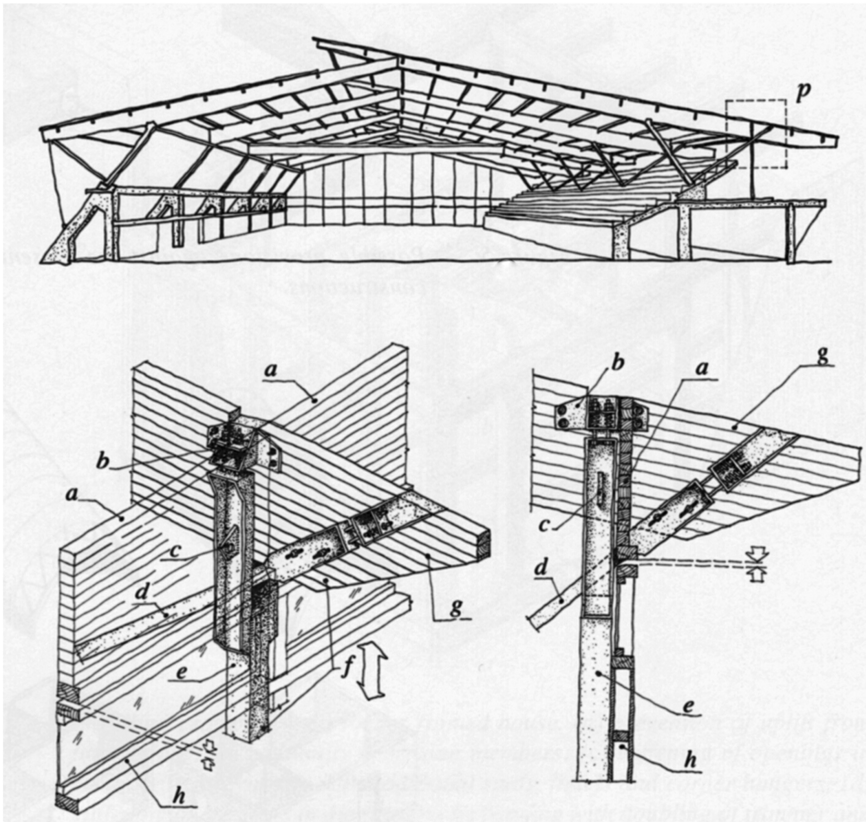

Figure 7 *Timber framed sport-hall with special joint allowing independent movements between structural and non-structural parts. In the enlarged detail (p) are visible: (a) frame stiffening beam; (b) heavy duty springs; (c) bracing system joint; (d) main frame steel rod with end spring; (e) building facade steel column; (f) independent movements between main frame and facade frame; (g) main frame glulam beam; (h) facade wooden frame and windows.*

The designer has two possibilities. One is to realise an external wall rigid, self-supporting and independent of the flexible timber structure, for example in Figure 7 the glass facade wall is independent of the main structure (Touliatos, 1991). The other possibility is to connect the external wall part, i.e. masonry, to the timber part so strictly that the two structures will act together as a composite structure. Actually in most cases the connections between external masonry walls and the internal timber structure are not accordingly conceived so that they just increase the horizontal action on the masonry wall because they add to the inertia forces acting on the wall per se, the pushing-action due to the larger movement of the timber structure.

If different material parts are connected, two simplified alternative design approaches are possible according to two different limit situations. On one hand it can be considered that the masonry weight should be carried by the timber structure (i.e. light masonry with mass but no rigidity, that means the masonry is considered fissured); on the other hand it may be assumed that the masonry, more rigid than timber, will collect the totality of lateral actions (i.e. heavy masonry). In other words the timber structure will still carry the vertical loads but will lean on the masonry structure with regard to the horizontal forces (Figure 8).

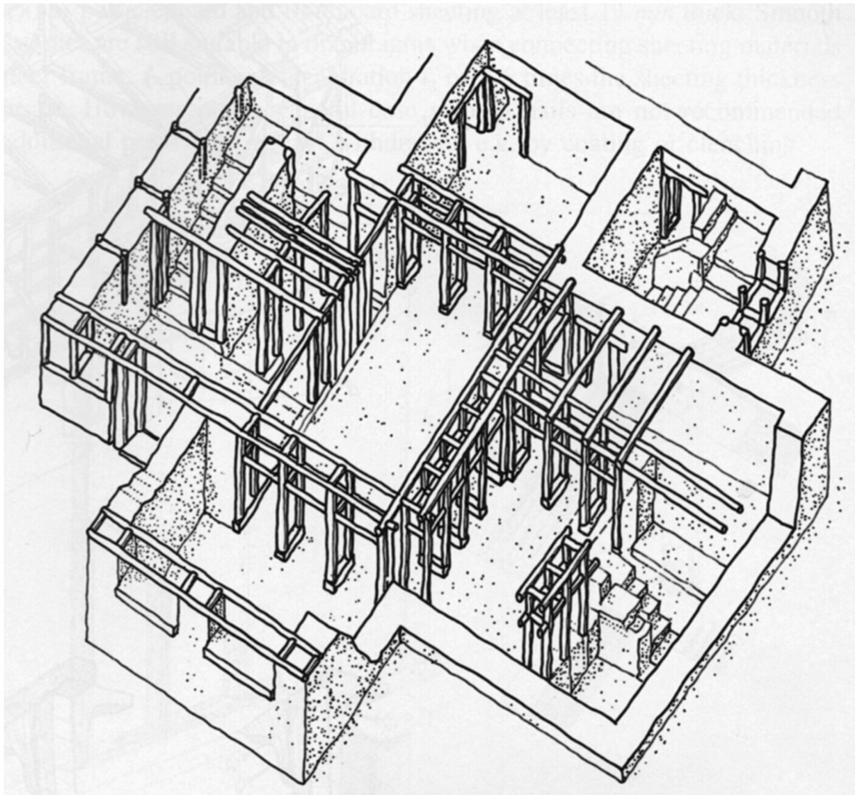

Figure 8 *Example of mixed stone-timber building (Greek Islands, 1500 B.C.). Timber framing supports vertical loads but only heavy masonry can resist lateral loads. Note that floors because of their workmanship cannot be considered rigid in plane.*

When a strong earthquake causes the masonry to collapse, dissipating a lot of energy, if detailing is well conceived, the timber structure has still the possibility to stand up after the shock and the masonry will be easily repaired, as shown in the case of Figure 9.

Ductility and dissipation of energy

In old buildings (e.g. timber framed buildings with brick infill, like in Figure 9), dissipation of energy was obtained by friction between timber and masonry, and by hysteresis due to compression perpendicular to grain (Touliatos, 1993). In modern structures, in order to reduce inertia forces, unless a decision is taken to increase the natural period of vibration as in Figure 7d, the most usual way is to dissipate energy by hysteresis in mechanical joints (see STEP lecture C17).

Eurocode 8 prescribes that when designing with reduced inertia forces ($q > 1$) ductility and energy dissipation properties shall be demonstrated by tests. For some particular cases tests may be avoided if certain details are followed. These details are mainly based on past experience.

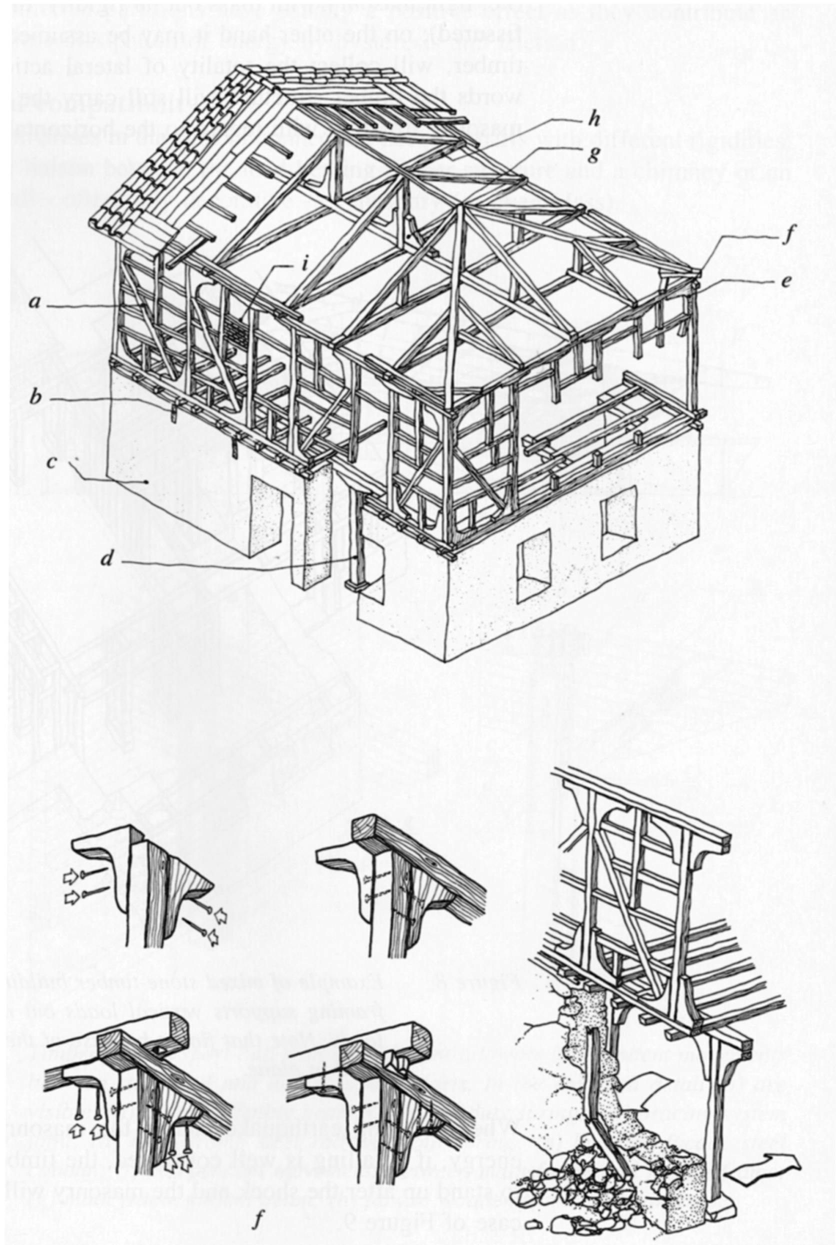

Figure 9 *Example of mixed masonry-timber structure building in Greek Islands (1800 A.D.). (a) diagonal stiffening timber rod acting perpendicular to grain at the corner; (b) anchoring detail of the wooden frame to the masonry wall; (c) masonry wall bearing the wooden frame of the upper floors; (d) secondary load bearing system of wooden columns, just behind the main load bearing system of masonry walls, able to support provisionally the entire structure after a severe earthquake (see the lower detail, right hand side); (e) wooden curved one piece component stiffening the timber wall frame; (f) special joint easy to replace when damaged after an earthquake (see the enlarged detail, below on the left hand side); (g) wooden curved one piece component stiffening the roof; (h) tie beam to avoid thrust on walls; (i) brick infill. Also in this case floors cannot be considered rigid in plane due to their workmanship.*

Nailed shear panel systems have given excellent ductile behaviour, much better than any diagonal bracing system. For that reason in the connection of sheeting to the timber framing, in Eurocode 8 it is stated that for proper ductility it is sufficient that the sheeting material is wood-based and the thickness t_1 of the sheeting material is at least 4 *d*, where *d*, the nail diameter, does not exceed 3,1 *mm*. This is valid provided that the wood-based materials meet one of the following conditions: particleboard-panels with a density of at least 650 kg/m^3, plywood-sheeting at least 9 *mm* thick, or particleboard and fibreboard sheeting at least 13 *mm* thick. Smooth nails and staples are still suitable in diaphragms when connecting sheeting materials to the timber frame. A point side penetration t_2 of 4-6 times the sheeting thickness is appropriate. However in the general case smooth nails are not recommended without additional provisions against withdrawal, e.g. by coating or clenching.

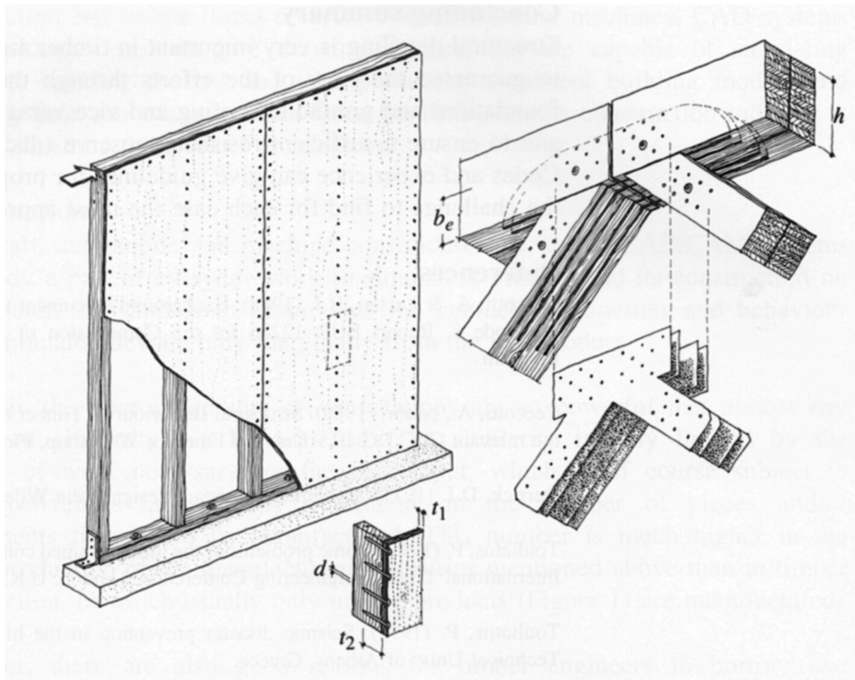

Figure 10 Basic detailing requirements in Eurocode 8.

Besides Eurocode 8 considers that dowelled and nailed timber-to-timber and steel-to-timber joints, when the minimum thickness of the connected members is at least 8 *d* and the dowel diameter does not exceed 12 *mm*, are sufficiently ductile. The reason why this applies is that for the best performance under cyclic load a mode III failure of the joint is desirable (that means thick timbers and slender dowels). Now, referring to the diagrams in STEP lecture C3 (see Figures 11 and 12) it is easy to recognise that the fields corresponding to the desirable behaviour are characterised by values of $t_1 / \sqrt{M_y / f_h\, d}$ and $t_2 / \sqrt{M_y / f_h\, d}$ ratios bigger than about 3,5. Therefore with reference to the usual values of timber embedding strength and fastener steel yielding strength it is possible to state that the minimum thickness of the connected timbers -8 *d*- is very much on the safe side, in ductility terms.

If a designer wants to propose different fastener arrangements or different materials, it is allowed, provided it can be demonstrated by tests that the EC8 performance requirements under cyclic loading of the joint are fulfilled (see STEP lecture C17). Obviously before proposing new arrangements it is important to have clearly in mind that the basic idea is to try to obtain a mode III failure in order to couple the dissipation due to the embedding of the timber with the dissipation due to the plasticity of the fastener's steel.

Note: it is evident that some detailing rules given by Eurocode 8 are thought to achieve the necessary ductility level. But what about the case when the designer chooses to design the structure without making reference to ductile and dissipative behaviour, i.e. with $q = 1$? In principle it is not essential, for example, to use slender dowels, but the use of slender dowels will for certain give to the structure a reserve of ductility that is always very welcome, without any extra cost. So the suggestion of the authors is to follow as much as possible the detailing for ductile and dissipative behaviour even for structures calculated as non dissipative.

Concluding summary

Structural detailing is very important in timber structures in seismic areas in order to guarantee the flow of the efforts through the entire resistant structure from foundations and ground to roofing and vice versa (structural form and continuity); and to ensure a sufficient resistance reserve (ductility and dissipation of energy). Codes and experience can give guidelines for proper detailing but the designer has the challenge to find for each case the most appropriate solution.

References

Ceccotti, A. & Larsen, H.J. (1988). Background Document for specific rules for timber structures in Eurocode 8. Report EUR 12226 for the Commission of the European Communities, Bruxelles, Belgium.

Ceccotti, A., editor, (1989). Structural Behaviour of Timber Constructions in Seismic Zones. Proc. of the relevant CEC DG III - Univ. of Florence Workshop, Florence, Italy.

Derrick, D.J. (1977). Earthquake resistant design. John Wiley & Sons pub., London, U.K.

Touliatos, P. (1991). Some problems of the timber framed construction in seismic zones. Proc. of 1991 International Timber Engineering Conference, London, U.K.

Touliatos, P. (1993). Seismic disaster prevention in the history of structures in Greece. National Technical Univ. of Athens, Greece.